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PHYSICAL PROPERTIES OF A FLY ASH SLURRY: A LABORATORY INVESTIGATION

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ABSTRACT

A laboratory testing program was undertaken to assess some physical properties of a fly ash slurry. The ash slurry was prepared by mixing 1-1/2 parts (by weight) of dry fly ash from Ontario Hydro's Nanticoke TGS and 1 part of water. Several types of tests were conducted to study the mixing, flowability, strength characteristics and the resistance to wind erosion of the fly ash. This report presents the testing data and recommendations regarding the viability of using a fly ash slurry for on-site disposal.

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PHYSICAL PROPERTIES OF A FLY ASH SLURRY: A LABORATORY INVESTIGATION

1.0 INTRODUCTION

At the request of Mr. D.K. Fung, Supervising Project Engineer for the Nanticoke TGS Ash Management Study, a laboratory testing program was carried out in the Civil Research Department to evaluate a number of physical characteristics of a pumpable fly ash slurry which is prepared by mixing ash and water. The main objective of this laboratory investigation was to obtain results on several important physical properties of the pumpable material so that a judicial decision regarding the practicality of pumping the ash slurry from a coal-fired generating station to a disposal site can be made. Also, the laboratory data can assist in designing the layout of a disposal site and in formulating the ash transporting/placement procedures.

2.0 LABORATORY STUDY

The laboratory specimens were prepared by first mixing a composite dry fly ash from Ontario Hydro's Nanticoke TGS with tap water in a mechanical mixer. A composite ash material was formed by mixing 70% of row "A" ash, 20% of row "B" ash and 10% of row "C" ash. The ash from row "A" of the ash precipitator was the coarsest-grained material, the ash from row "B" was finer and the ash from row "C" was the finest of all three ashes.

Figure 1 is the particle-size distribution curve of the composite fly ash. Table I presents the chemical composition of the fly ash.

The laboratory investigation mainly consisted of three parts:

- (1) a study on the effect of mixing fly ash and water without air bubbling and with air bubbling on the flow characteristics of the mix,
- (2) a study on the strength characteristics of the cured fly ash specimens, and
- (3) a study on the resistance of the cured ash specimens to wind erosion (ie dusting).

2.1 Mixing/Flowability

The mixing of 1-1/2 parts of dry fly ash and 1 part of water was done in a Hobart mixing bowl (Figure 2) at the speed of about 300 rpm. The mixing was initially done in two ways: (i) the ash was placed in the mixing bowl first and water was added later and (ii) water was placed in the mixer first and the fly ash added later. The flow property of these two types of mixes was measured by the "modified slump" test, which is described in Appendix I. It was found that the flowability of the mixes obtained by these two different mixing procedures was very similar. Therefore, it was decided to use procedure (ii) for mixing (ie water placed in the bowl first) as less fugitive dust would be generated during mixing in the laboratory.

For the mixing of fly ash and water with air bubbling, a new mixing container was made (Figure 3). A small loop made of plastic tubing with many perforated tiny holes was anchored at the base of the container and one end of the tubing was connected to a compressed air source. During the mixing of ash/water, air bubbles could be introduced in the slurry by opening up slightly the valve controlling the flow of the compressed air.

The flowability of the mixture of fly ash and water was measured by the modified slump test (Appendix I).

Table II summarizes the results of two groups of tests. The results of the first group of tests (1 & 2) indicate that the mix with air bubbling was slightly less flowable (ie pancake with a smaller diameter) than the mix without air bubbling. This was probably due to the slightly lower water content of the mix material, which could have been caused by the additional 5-minute mixing and/or the result of air bubbling. In the second group of tests (3 & 4), the same amount of mixing time (ie 5 minutes + 5 minutes) was used and the water content of the mix was measured immediately after the "modified slump" test. Again, it was found that the mix with air bubbling was slightly less flowable than that without air bubbling. This could be due to the slightly lower water content in the mix caused by air bubbling. It was concluded that during the mixing process the air bubbling facilitated the evaporation of water from the ash slurry, thus producing a mix with a slightly lower water content and reduced flowability.

It should be pointed out that even though there was a small difference observed in the flowability of the mixes prepared with and without air bubbling in the laboratory, it is estimated that this difference would not have a significant effect on pumping these two types of ash slurries in a pipe line.

2.2 Strength Characteristics

2.2.1 Unconfined Compressive Tests

In the mixing experiment, it was found that mixing with air bubbling only had a small effect on the flowability of the slurry. Therefore it was decided, for convenience, in most of the subsequent tests, that the ash slurry would be prepared without air bubbling. This decision would reduce the number of specimens to be tested.

The specimens for strength measurements were prepared by pouring the ash slurry into cylindrical cardboard containers (3" x 6") (Figure 4) and "cured" for a specific period of time in a room (temperature approximately 22°C) before testing. "Curing" is defined as the evaporation of water from a specimen and the taking place of slight pozzolanic reactions in the ash material. The compressive strength of a specimen was determined in an unconfined compression test (ASTM D2166)/1/. Table III and Figure 5 summarizes the pertinent data.

Some observations from the experimental data are listed as follows:

For Group I Tests (room-cured, undrained, no air bubbling)

- (1) The strength of a cured specimen was derived from the hardening of the ash due to evaporation of water from the ash and, to a lesser extent, due to the adhesion between the ash particles contributed by the pozzolanic reactions within the ash.
- (2) The water content (measured as per cent of dry ash by weight) of a cured specimen decreased as the "age" (days of curing) of the specimen increased.
- (3) The strength of a specimen increased with the specimen "age" due to the decreased water content in the ash. However, as more water was lost from the ash (lower water content), the material became very brittle and yielded a lower strength, instead of a higher strength (refer to the strength result of the 28-day specimen).
- (4) The decrease in the specimen height (initial height 15.3 cm (6")) due to drying was about 3%. It was noted that the shrinkage of the 28-day specimen was less than that of the younger specimens. This may be explained by the fact that the measurements were done on individual specimens and the shrinkage could vary slightly in different specimens. Also, the amount of shrinkage in the specimens was small and inaccuracies in length measurements could have contributed to the apparent inconsistency.
- (5) One cured specimen was cut into 3 pieces (top, middle and bottom) and particle analyses were done on these samples. The results are summarized in Figure 6, which show that there was practically no segregation of ash particles in a cylindrical specimen.

- (6) It is envisaged that the cured ash at the disposal site with strength comparable to that measured in the laboratory would be able to support vehicle loadings. Further, no stability problems are anticipated from this material.

For Group II Tests (room-cured, drained, no air bubbling)

- (1) These specimens were prepared with drainage allowed at the bottom of the containers. As a result, for specimens of the same age (ie 7 days), the water content of the "drained" specimen was lower than that of the "undrained" specimen (Group I tests).
- (2) The strength of the specimens increased with the "age" of the specimens and with a decrease in water content.
- (3) The amount of shrinkage was larger in Group II specimens than in Group I specimens. The shrinkage in the specimens was due to the evaporation of water from the upper end and the drainage of the water from the lower end of the specimens.
- (4) These data would indicate that it is advantageous to promote drainage of the ash slurry at a disposal site so that the cured ash would yield a higher strength.

For Group III Tests (room-cured, undrained, with air bubbling)

- (1) As mentioned previously in subsection 2.1, when the mixing of ash/water was done with air bubbling, the initial water content of the fresh ash slurry was lower than that of the slurry prepared without air bubbling. As the initial water content of the ash slurry was lower for this group of specimens, the water contents of the 4-day and 14-day specimens were therefore slightly lower than those of the comparable specimens in Group I (without air bubbling). The strength of these specimens was slightly higher because of lower water contents.
- (2) The shrinkage of these specimens did not seem to be different from those of the Group I specimens.

For Group IV Tests (frozen, undrained, no air bubbling)

- (1) When the water was frozen in the ash slurry, the specimens behaved like a piece of ice. It was felt that the unconfined compression tests would not render meaningful data for the frozen specimens and the tests were not carried out.
- (2) When the ice in the specimen turned into water at room temperature, the specimen became soggy and could not even support its own weight (Figure 7). The strength of the specimen was too low to be determined by a laboratory compression test.
- (3) When the ash slurry is pumped to a disposal site in the winter in Ontario, it is expected that the ash layer will be frozen in a relatively short time. In the frozen state, the material would be quite strong.

During the winter season, layers of frozen ash slurry would build to one to several meters thick. In the spring time, this frozen material would thaw and become very soggy. As this thawed material has very low strength, it would not be stable within the disposal area unless drainage is provided to quickly drain the excess water in the thawed material. In the design of a disposal site, it is imperative that this provision is incorporated.

2.2.2 Re-worked Cured Ash

It has been suggested that the cured ash (partially dried ash slurry) may be excavated from the disposal site and would be used as a fill to build the retaining dyke (or berm) around the disposal area. Therefore, a visual examination was done in the laboratory on the broken pieces of ash from a 28-day old specimen. Figure 8 shows the sample. It was concluded that the cured ash behaved like a brittle material which could be crushed easily. The finely crushed ash appeared no different from the original ash material which was used to prepare the test specimen. It may be concluded that there are no real advantages in using the re-worked ash excavated from the disposal site to build the retaining dyke. If it is proposed to use fly ash as a construction material for the retaining dyke, fly ash mixes with some water may be used instead. This ash may be compacted at a specified water content or be stabilized with a small quantity (eg 5%) of cement when the material is used to build a retaining dyke.

2.2.3 Cured Ash Submerged in Water

A 7-day cured specimen was submerged in water to investigate the stability of the material in water. Figure 9(a) shows that partial slumping of the material occurred a few hours after the specimen was submerged in water. Figure 9(b) illustrates that the specimen turned into a pile of loose ash after 3 days of submersion of the specimen. However, in a similar experiment, an "older" specimen (about 50 days) was used. Very little slumping occurred in the five-day testing period. It may be concluded that the "older" specimen which possessed a higher strength and possibly was less permeable to water, would not "disintegrate" in water even under the unconfined condition.

Limited results from this experiment would point to the necessity of providing confinement to the cured ash at the disposal site to avoid the possibility of ash slumping if the ash is in contact with a pond of surface water.

2.3 Wind Tunnel Experiment

The resistance of the cured fly ash slurry to wind erosion is a very important property to be considered in deciding whether it is beneficial to transport fly ash by pumping ash slurry to a disposal site. Much effort in this laboratory investigation was therefore focused on the study of this property of the cured fly ash under various anticipated field conditions.

To study the ability of the cured ash to resist wind erosion, a small wind tunnel was used to investigate the extent of dusting as a result of wind erosion to the ash surface. Figure 10 shows the equipment/2/.

The test specimens were prepared by first mixing 1-1/2 parts of fly ash with 1 part of water according to the procedure described previously. No air bubbling was used in preparing the ash slurry, which was then poured into metal pie pans ($\emptyset = 230$ mm). Then the specimens were cured according to a number of predetermined conditions before they were placed in the wind tunnel for the erosion tests. In the group I tests, the ash slurry was poured into a pie pan and formed a cone above the rim of the pan. As the ash slurry had a low consistency, it was only possible to form a cone with a crown of about 2.1 cm at the centre above the rim of the pan. In the Group II tests, specimens with a higher crown were used. The height at the centre of the cone was about 5.1 cm above the rim of the pan (Figure 11). This group of specimens would have a larger exposed surface to wind erosion. Also, when this specimen was placed in the wind tunnel, it was possible to obtain a high wind velocity at the specimen location.

In order to prepare a specimen with a higher cone, it was necessary to make a cardboard form in the shape of a cone which was temporarily attached to the rim of a pie pan. Then the ash slurry was poured through a small hole at the crown of the cardboard cone in several steps to build up the ash cone gradually.

A wind erosion test on a specimen was conducted by placing the ash specimen in the wind tunnel (Figure 10). Then the electric fan would be started to blow air over the ash surface of the specimen for a certain time period. The difference in the weights of the specimen before and after the wind tunnel test would indicate the severeness of wind erosion on the ash surface.

Initially, wind erosion tests were done on dry fly ash very loosely placed in a pie pan. The specimens were arbitrarily subjected to 30 minutes wind erosion in the tunnel. It was expected that dusting would be very severe for these loose dry ash specimens and the test results would be used as a reference on the extent of wind erosion. Figure 12 showing different amounts of loose dry ash provides an appreciation of the extent of wind erosion in 30 minutes.

In Group I tests, the measured wind velocity was 50 km/h directly above the crown of the specimen. In Group II tests, the measured wind velocity was 55 km/h. (It was not possible to achieve higher wind velocities in this small wind tunnel.) According to the wind data collected by Morrison Hershfield Limited/3/ at two weather stations near the Nanticoke TGS, the wind velocity was greater than 50 km/h in less than 2% of the time. However, at the Nanticoke fly ash lagoon site, the wind would probably be stronger due to the open topography of the site and its proximity to Lake Erie.

Many wind tunnel tests were performed on various types of ash specimens under a variety of simulated field conditions. These tests may be broadly grouped as follows:

- (1) Fly ash slurry specimens cured (partially dried) at room temperature to simulate the drying of the slurry in the field during non-winter months (air temperatures above zero).

- (2) Fly ash slurry specimens subjected to freezing at a temperature equal to -10°C to simulate winter conditions.
- (3) Fly ash slurry specimens arbitrarily subjected to 5 cycles of freezing and thawing (30 minutes each cycle) to simulate freezing and temporary thawing in winter months.
- (4) Compacted fly ash specimens subjected to partial drying at room temperature or subjected to freezing at a temperature of -10°C .

A comparison of all the test results would indicate whether the ash slurry specimens are superior to compacted ash specimens in terms of their resistance to wind erosion.

A summary of the data obtained from the Group I tests and Group II tests is contained in Tables IV and V.

General comments and conclusions based on these results are presented as follows:

- (1) The surface of room-cured ash slurry specimens after 1 day or several days of drying was quite hard and crusty with some cracks. The weight loss of a specimen after it was subjected to wind erosion for 30 minutes was usually small. Note that the weight loss of the specimen was due to the evaporation of water from the specimen and the removal of some ash particles from the specimen surface. (Refer to Tests I-4(a), I-5(a), I-6(a), II-6(a)(b).)

It may be concluded that only minor dusting would be expected for the partially dried ash slurry in the field.

- (2) In comparison, room-cured (partially-dried) compacted fly ash (25% water content, 1200 kg/m^3 dry density) showed more dusting than room-cured ash slurry (refer to Test II-3(a)). Compacted fly ash, if disturbed slightly (eg by a finger on the ash surface), was also more prone to wind erosion than room-cured ash slurry.
- (3) When a fly ash slurry specimen was frozen at a temperature of -10°C , a needle-like pattern would develop on the specimen surface (Figure 14). When the frozen specimen was subjected to wind erosion, very minor dusting was observed (refer to Tests I-7(a), I-8(a), I-9(a), I-10(a), I-11(a), I-12(a), and II-5(a)).

However, when the frozen ash surface was slightly disturbed (eg by moving a finger across the ash surface), the loosened ash particles (Figure 15) would be easily removed by wind, causing medium to severe dusting. (Refer to Tests I-9(b), I-10(b), I-11(b), I-12(b) and II-5(b).) It was observed that the ash layer showing the needle-like pattern was quite thin.

- (4) When the frozen ash slurry specimens were subjected to 5 cycles of freezing and thawing (30 minutes freezing and 30 minutes thawing), the ash surface became slightly more susceptible to wind erosion, presumably due to some disturbance to the ash particles. (Refer to Tests I-7(b), I-8(b), I-10(c) and I-11(d).)
- (5) To determine the effect of rain on an ash slurry specimen initially frozen then cured at room temperature, Tests II-7 were done. It was observed that freezing of the ash first created the needle-like pattern on the specimen surface. When the surface was partly dried at a temperature about zero and then was disturbed by spraying water ("rain"), the ash particles could be eroded more easily by wind when they are dried.

It was also observed in Test II-6(c) that disturbance to the ash surface by simulated rain drops would increase the wind erosion potential of the ash surface.

3.0 SUMMARY AND CONCLUSIONS

A laboratory investigation was carried out to study some of the physical properties of a fly ash slurry (1-1/2 parts ash and 1 part water). The study consisted of 3 parts: the effect of air bubbling on mixing of fly ash and water, the strength characteristics of the cured fly ash slurry specimens and the wind erosion potential of fly ash specimens cured at different temperatures and tested under various simulated field conditions.

From the limited laboratory data, a number of conclusions can be drawn:

- (1) Mixing fly ash and water with air bubbling caused a slight decrease in the initial water content of the fresh slurry, presumably due to the fact that air bubbling would promote more evaporation of water from the slurry. As a result, the fresh slurry prepared with air bubbling was slightly less flowable than the slurry prepared without air bubbling.
- (2) The strength of partially air-dried ash specimens at temperatures above freezing would be sufficient at the disposal site not to cause any stability problems to the retaining dyke. (It is assumed that the ash slurry is disposed of at an above-ground site surrounded by a retaining dyke.)
- (3) The strength of a thawed ash material initially frozen would be quite low. Attention should be given in designing a disposal site with the provision of drains so that the large quantity of water in the thawed ash would be drained quickly.
- (4) The ash slurry partially dried at temperatures above zero (eg summer/fall seasons in the field) should have little dusting problems. However, it is important to minimize any mechanical disturbance to the ash surface so that loosening of the ash particles can be avoided.

- (5) The ash slurry cured at room temperatures showed more resistance to wind erosion than conventionally-compacted fly ash (moisture 25%, dry density 1200 kg/m³).
- (6) The frozen ash slurry (at temperature of -10°C) had little dusting problem. However, slight mechanical disturbance to the surface would loosen up a thin layer of ash causing a more significant dusting problem.
- (7) Events such as raining, temperature fluctuations (resulting freezing/thawing) would cause some disturbance to the ash surface and increase slightly the amount of erosion by wind.

A number of recommendations may be made on the experience gained in this laboratory study.

- (1) Laboratory results have indicated that in terms of wind erosion, the cured ash slurry is superior to the conventionally-compacted fly ash. In order to verify some of the merits and short-comings of the ash slurry, a field demonstration project should be carried out over a period of several seasons.
- (2) In designing the disposal site, the properties and behaviour of the cured ash slurry should be considered to minimize anticipated problems (eg dusting) in the field.
- (3) To minimize the fugitive dust from a fly ash disposal site, it is important to keep the disturbance to the ash surface to the minimum. For instance, the ash surface should not be disturbed by moving vehicles. To achieve this, a large disposal site would be subdivided into many smaller disposal cells. The ash slurry would then be pumped into one cell at one time until the cell is full. Then provisions should be made to protect the ash surface so that dusting can be minimized.

ACKNOWLEDGMENTS

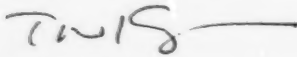
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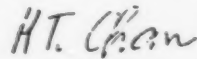
Messrs A. Morton and J. Jones of the Civil Research Department performed the laboratory tests reported in this report. Their assistance is also gratefully acknowledged.

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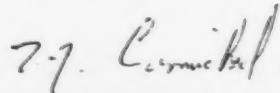
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REFERENCES

1. ASTM (1985) Annual Book of ASTM Standards, Section 4 (Construction), Vol 04.09, pp 338-341.
2. Toth, P.S. (1987) Wind Tunnel Testing of Fly Ash Dust Control Agents Under Winter Conditions. Ontario Hydro Research Division Report No S87-24-H, June 29, 1987.
3. Morrison Hershfield Limited. Dust Dispersion Study for Nanticoke TGS Ash Lagoon, Nanticoke, Ontario. Report 48516182, February 26, 1986.
4. R. Dayal (1989) Private communication with Dr. Dayal of the Civil Research Department.

TABLE I
Chemical Composition of Fly Ash From Nanticoke TGS

<u>Major Elements</u>		<u>Trace Elements</u>	
SiO ₂	44.77% by weight	Nb	20 mg/kg
TiO ₂	0.69	Zr	250
Al ₂ O ₃	16.38	Y	49
Fe ₂ O ₃	18.89	Sr	888
MnO	0.08	Rb	49
MgO	1.19	Pb	27
CaO	6.01	Zn	61
K ₂ O	0.72	Cu	60
P ₂ O ₅	0.20	Ni	52
Na ₂ O	0.0	Co	31
LOI*	10.98	Cr	83
SO ₃	1.82	Ba	1912
		V	126
		Ga	24

*at 950°C, SO₃ included in LOI

TABLE II

Flowability Measurements on Mixtures of 1-1/2 Parts of Fly Ash
and 1 Part of Water Without and With Air Bubbling

Test	Mixing	Diameter of* Slumped Sample (mm)	Water Content (%)		Mixing Procedure	Comments
			Immediate	4 days 14 days		
1	without air bubbling	330	-	60 45	- 5 minutes in the Hobart mixing bowl	- tests 1 and 2 were done by the same technician - mixing procedure for tests 1 and 2 is slightly different
2	with air bubbling	310	-	57 42	- 5 minutes in the Hobart mixing bowl - the mix was poured in the second mixing bowl and mixed with air bubbling for an additional 5 minutes	
3	without air bubbling	310	65	-	- 5 minutes in the Hobart mixing bowl - the mix was poured in the second mixing container and mixed without air bubbling for an additional 5 minutes	- tests 3 and 4 were done by the same technician, was not the one doing tests 1 and 2 - mixing procedure for tests 3 and 4 is identical
4	with air bubbling	298	63.6	-	- same as test #2	

*slumped sample (Pancake-like) with a larger diameter is more flowable

TABLE III

Summary of Compressive Strength of Cured Fly Ash Slurry Specimens

Group of Tests	Description of Specimens	Age (Days)	Average Compressive Strength (kPa)	Average Water Content (%)	Shrinkage Reduction** (%)	Remarks
I	- room-cured at $t = 22^{\circ}\text{C}$	4	66	60	3	specimen very dry and brittle
	- no drainage at the bottom of mold	7	78	57	4	
	- no air bubbling during	14	99	45	3	
		28	92	45	3	
II	- room-cured	4	47	55	2	
	- drainage at the bottom of mold	7	83	51	7	
	- no air bubbling during mixing of slurry	14	116	27	8	
III	- room-cured	4	70	57	4	
	- no drainage at the bottom of mold	14	108	42	2	
	- air bubbling					
IV	- frozen at $t = -10^{\circ}\text{C}$	4	N/A	60	-	specimen not able to support own weight when thawed no shrinkage specimens expanded slightly during freezing
	- no drainage at the bottom of mold	5	N/A	60	-	
	- no air bubbling					

* average of two specimens

**shrinkage expressed in % initial specimen height

TABLE IV

Summary of Wind Tunnel Test Results (Group I Tests)

(Specimens 1.2-cm high crown at the centre. Exposed surface area = 413 cm² (64 in²)).
Wind Velocity = 50 km/h

<u>Test</u>	<u>Specimen</u>	<u>Simulation of Field Conditions</u>	<u>Weight Loss in Grams</u>	<u>Observations and Comments</u>
I-1	- dry fly ash very loosely placed		19.8	- severe dusting test results used as a reference of the severeness of dusting
I-2	- dry fly ash very loosely placed		50.2	- severe dusting
I-3 (a)	- compacted fly ash 25% moisture content dry density 1200 kg/m ³ - specimen frozen immediately for 3 days	- compacted ash frozen in winter	1.6	- practically no dusting - dry density
I-3 (b)	- ash surface disturbed by moving a finger spirally on the surface of the specimen from the centre to the edge	- compacted ash frozen in winter - ash surface later disturbed	9.1	- minor dusting
I-4 (a)	- mixture of 1.5 parts of ash and 1 part of water (same mix for tests I-5 to I-14) - specimen room-cured for 7 days - no drainage at the bottom of the container	- ash cured in the summer or fall season	2.4	- hard, crusty surface - very minor dusting

TABLE IV (cont'd)

<u>Test</u>	<u>Specimen</u>	<u>Simulation of Field Conditions</u>	<u>Weight Loss in Grams</u>	<u>Observations and Comments</u>
I-4 (b)	- ash surface disturbed spirally by a finger	- minor disturbance of the ash surface	2.4	- practically no dusting/very minor dusting
I-5 (a)	- specimen room-cured for 7 days - some drainage at the bottom of the container	- ash cured in the summer or fall	0.5	- hard, crusty surface - no dusting
I-5 (b)	- ash surface disturbed spirally by a finger	- minor disturbance of the ash surface	2.3	- practically no dusting/very minor dusting
I-6 (a)	- specimen room-cured for 28 days - no drainage at the bottom of the container	- ash cured in the summer or fall season	0.6	- no dusting - hard, crusty surface
I-6 (b)	- ash surface disturbed spirally by a finger	- minor disturbance of the ash surface	0.3	- no dusting
I-7 (a)	- frozen at $t = -10^{\circ}\text{C}$ for 1 day - no drainage at the bottom of the container	- ash cured in the winter	1.6	- practically no dusting - needle-like structure on ash surface
I-7 (b)	- 5 cycles of freezing (30 mins) & thawing (30 mins)	- freezing and thawing	4.2	- very minor dusting

TABLE IV (cont'd)

<u>Test</u>	<u>Specimen</u>	<u>Simulation of Field Conditions</u>	<u>Weight Loss in Grams</u>	<u>Observations and Comments</u>
I-8 (a)	- frozen at $t = -10^{\circ}\text{C}$ for 1 day - no drainage at the bottom of the container	- ash cured in the winter	2.9	- practically no dusting
I-8 (b)	- 5 cycles of freezing and thawing	- freezing and thawing	6.7	- very minor dusting
I-9 (a)	- frozen at $t = -10^{\circ}\text{C}$ for 1 day - no drainage at the bottom of the container	- ash cured in the winter	1.1	- no dusting - needle-like structure on ash surface
I-9 (b)	- ash surface disturbed spirally by a finger	- minor disturbance of the ash surface	4.0	- very thin layer of ash disturbed
I-10 (a)	- frozen at $t = -10^{\circ}\text{C}$ for 1 day - no drainage at the bottom of the container	- ash cured in the winter	0.8	- no dusting
I-10 (b)	- ash surface disturbed by a finger	- minor disturbance of the ash surface	12.1	- medium dusting
I-10 (c)	- 5 cycles of freezing and thawing	- freezing and thawing	2.4	- very minor dusting

TABLE IV (cont'd)

<u>Test</u>	<u>Specimen</u>	<u>Simulation of Field Conditions</u>	<u>Weight Loss in Grams</u>	<u>Observations and Comments</u>
I-11 (a)	- frozen at $t = -10^{\circ}\text{C}$ for 7 days - no drainage	- ash cured in the winter	3.7	- very minor dusting
I-11 (b)	- ash surface disturbed spirally by a finger	- minor disturbance of the ash surface	35.8	- ash particles loosen causing severe dusting
I-11 (c)	- practically all loose particles removed from the surface before tests		1.5	- the ash below the disturbed ash layer was quite resistant to dusting
I-11 (d)	- 5 cycles of freezing and thawing	- freezing and thawing	4.6	- very minor dusting
I-12 (a)	- frozen at $t = -10^{\circ}\text{C}$ for 3 days - drainage allowed at the bottom of the pan	- ash frozen in winter	0.4	- no dusting
I-12 (b)	- ash surface disturbed spirally by a finger	- ash surface disturbed	12.7	- medium dusting
I-13 (a)	- ash from Nanticoke ash lagoon (ie "washed" ash) - frozen for 3 days at $t = -10^{\circ}\text{C}$ - no drainage allowed at the bottom of the pan	- ash frozen in water - ash frozen in water	1.6	- practically no dusting - ash particles of the "washed" ash slightly coarser than the the Nanticoke dry ash
I-13 (b)	- ash surface disturbed spirally by a finger	- ash surface disturbed	9.1	- minor dusting

TABLE IV (cont'd)

<u>Test</u>	<u>Specimen</u>	<u>Simulation of Field Conditions</u>	<u>Weight Loss in Grams</u>	<u>Observations and Comments</u>
I-14	- frozen at $t = -10^{\circ}\text{C}$ in wind tunnel for 2 hours to remove moisture - frozen for 1 day	- cold wind removing some moisture from the ash - ash is frozen	1.0	- practically no dusting

TABLE V

Summary of Wind Tunnel Test Results (Group II Tests)

(Specimens 5.1-cm high crown at the centre. Exposed surface area = 458 cm² (71 in²))
 Wind Velocity = 55 km/h)

<u>Test</u>	<u>Specimen</u>	<u>Simulation of Field Conditions</u>	<u>Weight Loss in Grams</u>	<u>Observations and Comments</u>
II-1	- dry fly ash very loosely placed		64.4	- severe dusting - test result used as a reference of the severeness of dusting
II-2	- dry fly ash very loosely placed		127.8	- severe dusting
II-3 (a)	- compacted ash 25% moisture - dry density 1200 kg/m ³ (75 lbs/ft ³) - specimen cured at room temperature for 1 day	- partially dry compacted fly ash at disposal site at temperature above zero	24.7	- surface crumbly - medium to severe dusting
II-3 (b)	- ash disturbed by moving a finger spirally on the surface of the specimen from the centre to the edge	- partially dry compacted fly ash disturbed on the surface (eg by moving vehicles)	76.4	- Ash particles loosened by disturbance with a finger. Much more disturbance may be caused by a wire brush. - severe dusting

TABLE V (cont'd)

<u>Test</u>	<u>Specimen</u>	<u>Simulation of Field Conditions</u>	<u>Weight Loss in Grams</u>	<u>Observations and Comments</u>
II-4 (a)	- compacted at 25% moisture content - dry density 1200 kg/m³ - specimen frozen for 1 day	- compacted ash frozen in winter	0.4	- no dusting
II-4 (b)	- ash surface disturbed by a finger	- frozen ash disturbed	21.5	- medium to severe dusting
II-4 (c)	- same specimen frozen for 3 days (loose ash particles due to disturbance were re-moved in day 1) at t = -10°C	- compacted ash frozen	0.9	- no dusting
II-4 (d)	- ash surface disturbed	- compacted ash frozen and disturbed	51.5	- severe dusting ash particles on the surface loose and fairly dry
II-5 (a)	- fly ash slurry (1-1/2 parts of ash and 1 part of water) - no drainage - frozen for 1 day at t = -10°C	- no drainage - ash frozen in winter	1.1	- no dusting
II-5 (b)	- ash surface disturbed	- frozen and disturbed	23.0	- medium to severe dusting

TABLE V (cont'd)

<u>Test</u>	<u>Specimen</u>	<u>Simulation of Field Conditions</u>	<u>Weight Loss in Grams</u>	<u>Observations and Comments</u>
II-6 (a)	- fly ash slurry cured at room temperature for 7 days (same mix for test II-7)	- fly ash dried in the warm season	6.0	- surface of specimen crusty
II-6 (b)	- cured for 9 days		5.0	
II-6 (c)	- at 10 days sprayed water on ash specimen - at 13 days dried at room temperature	- raining	10.0	
II-6 (d)	- at 15 days		5.0	
II-6 (e)	- at 17 days		4.0	
II-6 (f)	- at 21 days		1.0	
II-7 (a)	- fly ash slurry frozen for 5 days	- ash frozen in winter	1.0	- needle-like structure on the ash surface
II-7 (b)	- specimen cured at room temperature for 8 days - then water sprayed on ash surface - air dried for 2 days	- disturbance by rain	34.0	
II-7 (c)	- air dried another 4 days		2.0	



FIGURE 2
MECHANICAL MIXER USED TO
PREPARE FLY ASH SLURRY



(a)



(b)

FIGURE 3

**(a) MIXING CONTAINER WITH
A PLASTIC PERFORATED
LOOP ATTACHED FOR
AIR BUBBLING**

**(b) MIXING ASH/WATER WITH
A MOTORIZED WHEEL
PADDLE**



FIGURE 4

**SPECIMENS FOR COMPRESSIVE STRENGTH TESTS
ARE BEING PREPARED.
(SPECIMEN SIZE 7.5 cm (3") IN DIAMETER AND
15 cm (6") IN HEIGHT)**

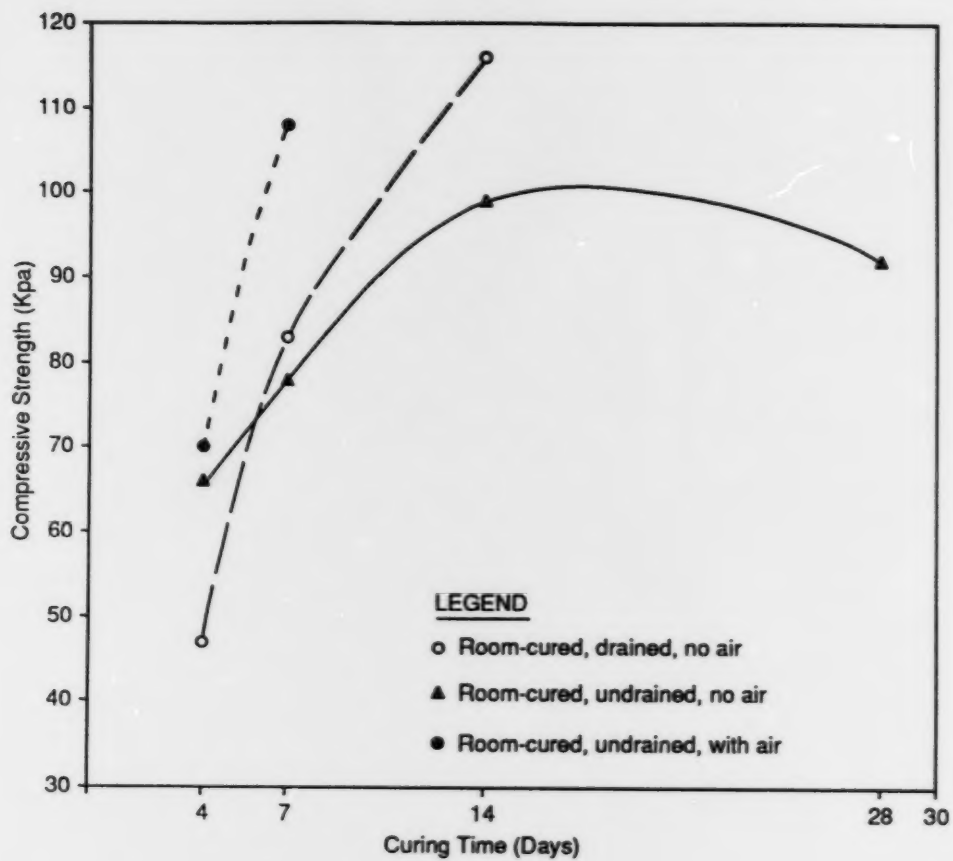


FIGURE 5
COMPRESSIVE STRENGTH VS. CURING TIME FOR
3" x 6" SPECIMENS PREPARED UNDER DIFFERENT CONDITIONS

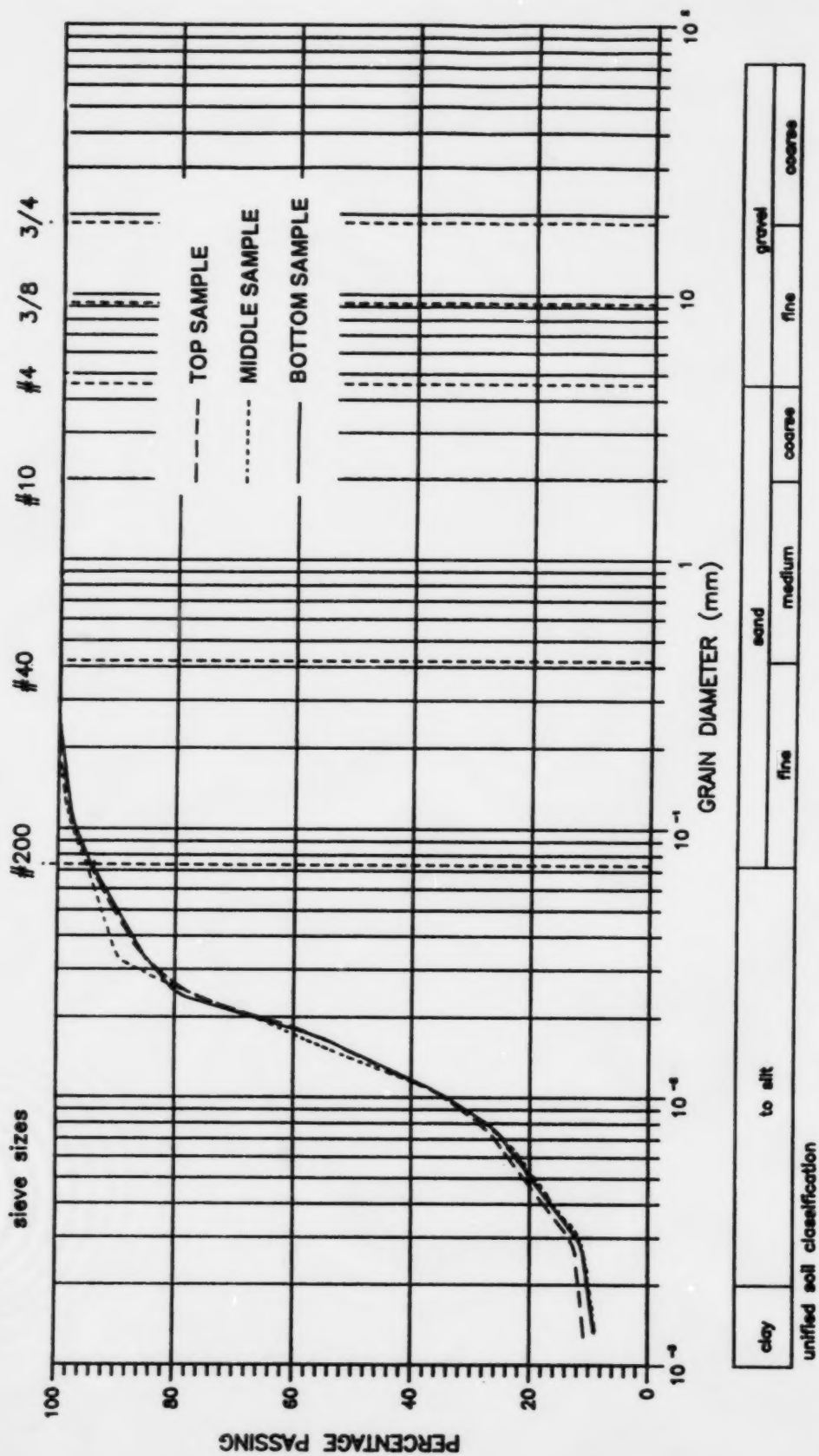


FIGURE 6
PARTICLE SIZE DISTRIBUTION OF THE TOP, MIDDLE AND BOTTOM
SECTIONS OF A CURVIED FLY ASH SPECIMEN

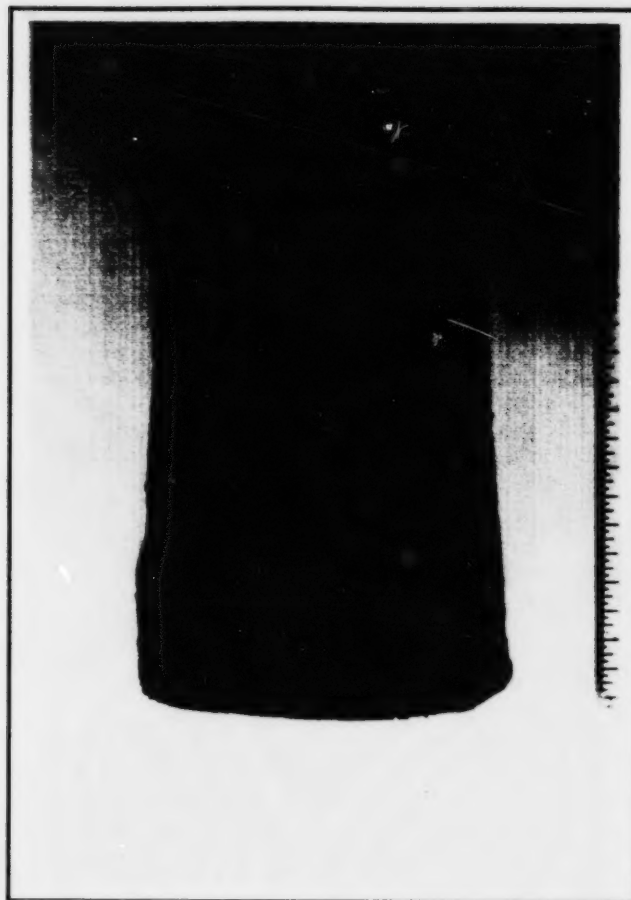


FIGURE 7

**A THAWED FLY ASH SPECIMEN
BULGING AT THE LOWER END,
INDICATING THE INABILITY OF THE
SPECIMEN TO SUPPORT
ITS OWN WEIGHT**



FIGURE 8

**CRUSHED FLY ASH SPECIMEN WITH
VERY LOW WATER CONTENT**

180513-811-RD

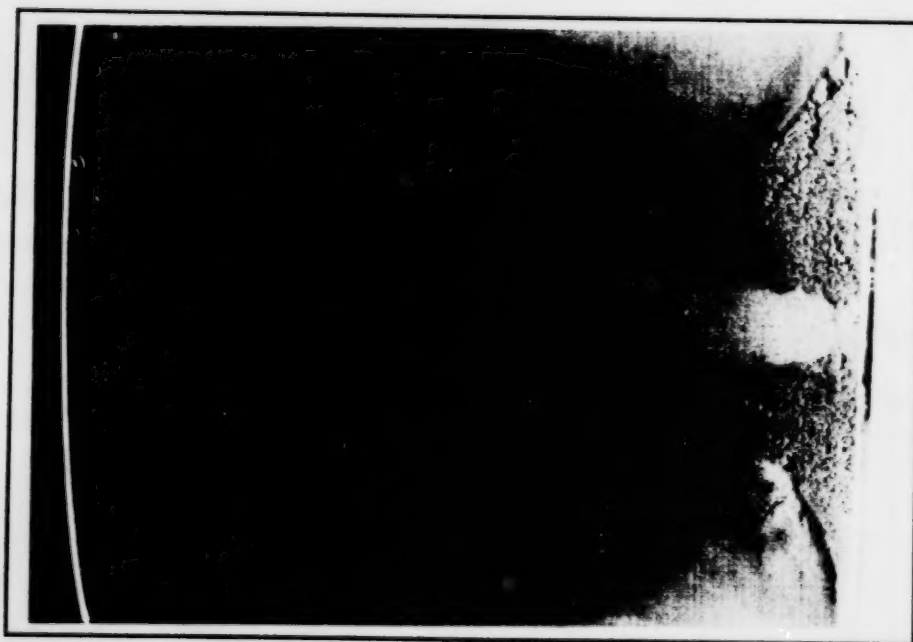


FIGURE 9

(a) SLUMPING OF A 7-DAY OLD, ROOM-CURED SPECIMEN AFTER SUBMERGED IN WATER FOR SEVERAL HOURS

(b) DISINTEGRATION OF ASH SPECIMEN IN WATER AFTER 3 DAYS

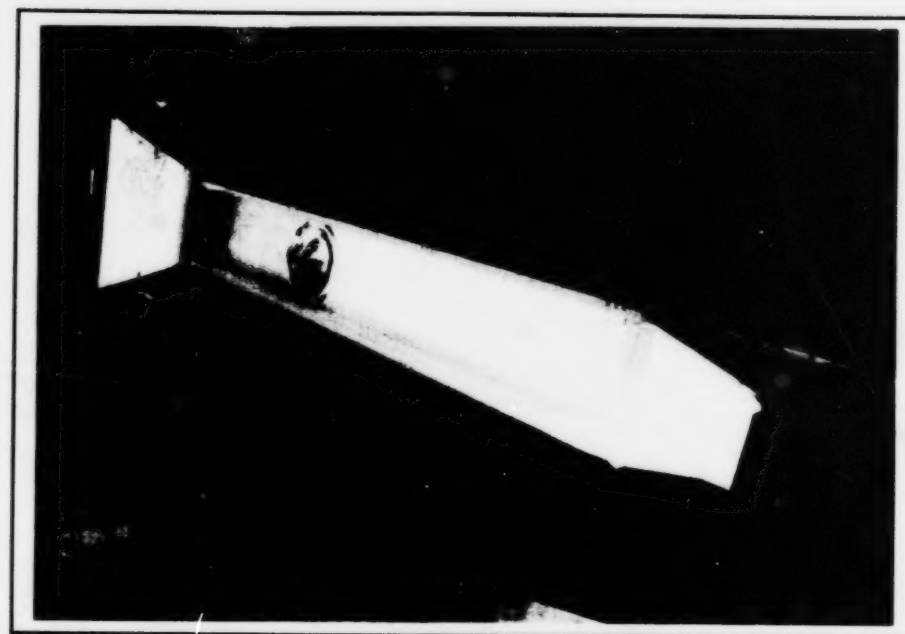
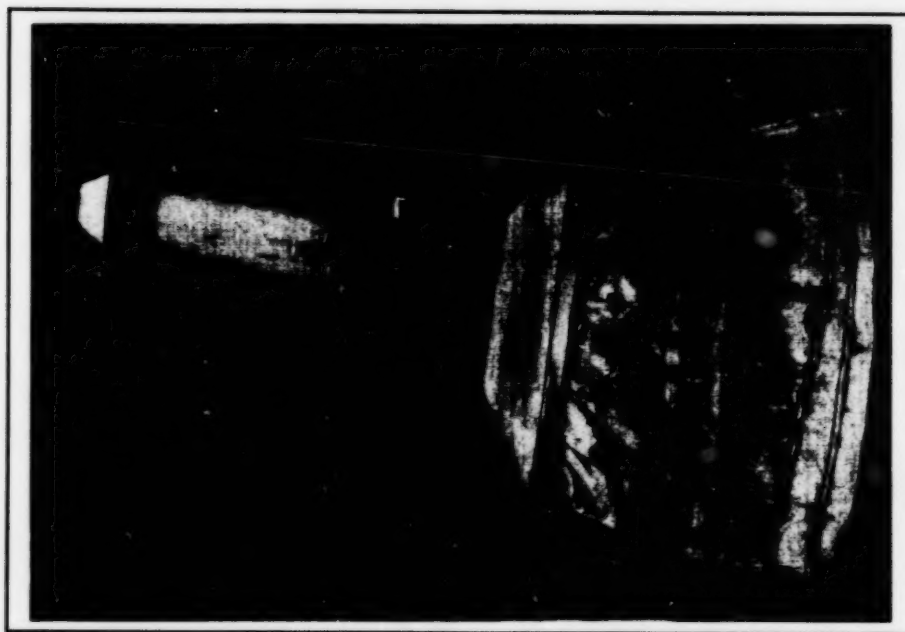


FIGURE 10
WIND TUNNEL EQUIPMENT
(LENGTH OF RECTANGULAR
SECTION = 1.83 m, HEIGHT = 100 mm, WIDTH = 250 mm)

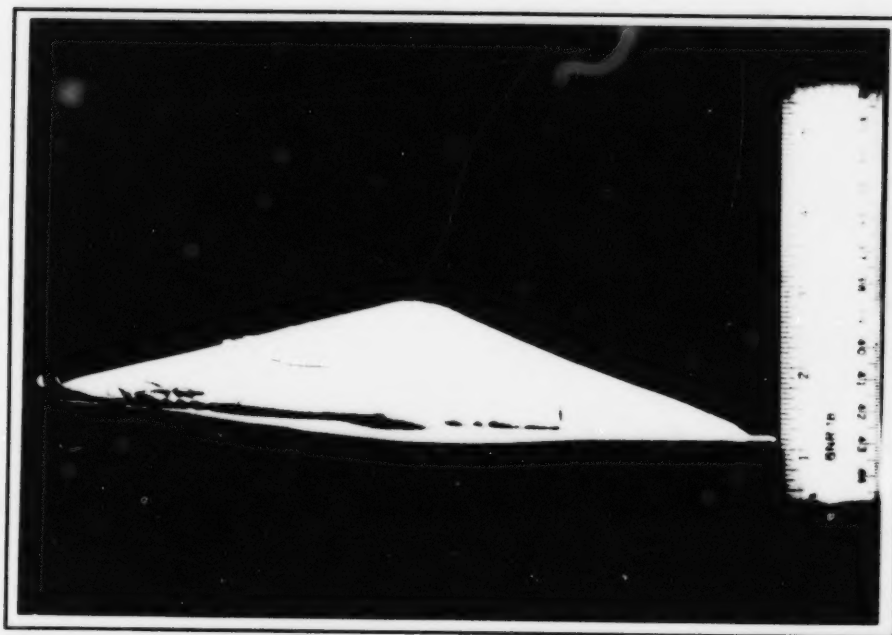


FIGURE 11

**PROFILE OF A CURED FLY ASH SPECIMEN IN A PIE PAN
(HEIGHT OF THE CONE ABOVE THE RIM IS ABOUT
51 mm, THE DIAMETER OF THE PIE PAN IS 230 mm)**

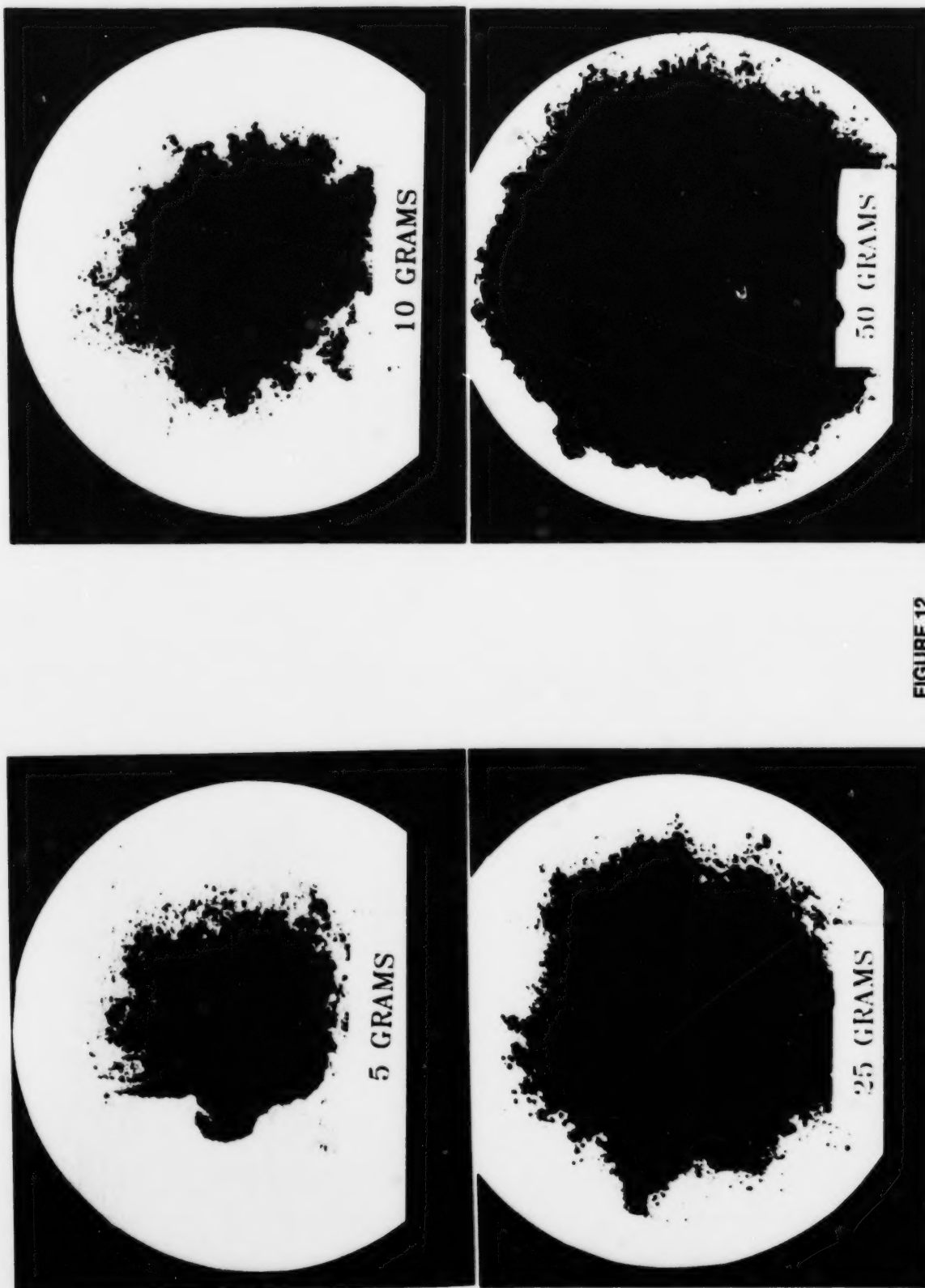
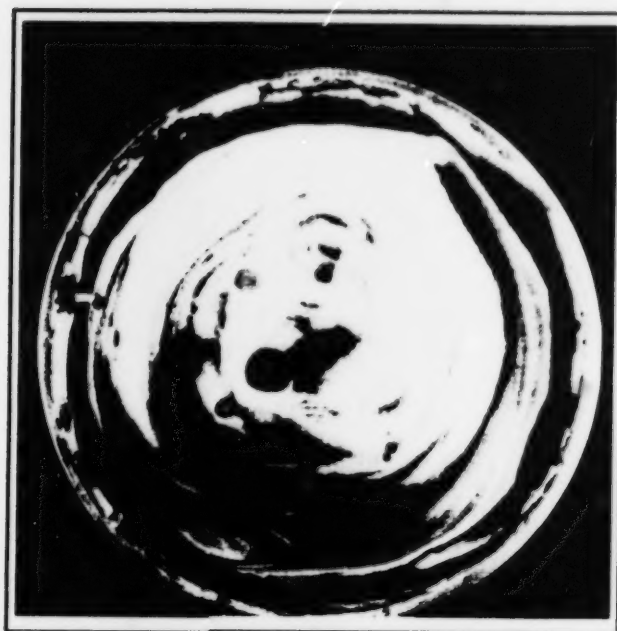


FIGURE 12

VISUAL COMPARISON OF VARIOUS AMOUNTS OF ERODED DRY FLY ASH
FROM SPECIMENS IN 30 MINUTES

180517-B11-RD

(a)



(b)



FIGURE 13

**ROOM-CURED FLY ASH
SLURRY SPECIMEN
WHITE POWDER MATERIAL
ON THE SURFACE OF
THE SPECIMEN IS
PROBABLY CALCIUM SALT**

**(a) 1-DAY ROOM-CURED
SPECIMEN**

**(b) CLOSE-UP OF THE
ASH SURFACE WITH
CRACKS**

180518-B11-RD

(a)



(b)



FIGURE 14

**FROZEN FLY ASH SPECIMEN SHOWING A
NEEDLE-LIKE PATTERN ON THE SURFACE**

(a) SPECIMEN FROZEN FOR 1 DAY

**(b) NEEDLE-LIKE PATTERN ON THE
SURFACE OF THE SPECIMEN**

180519-B11-RD

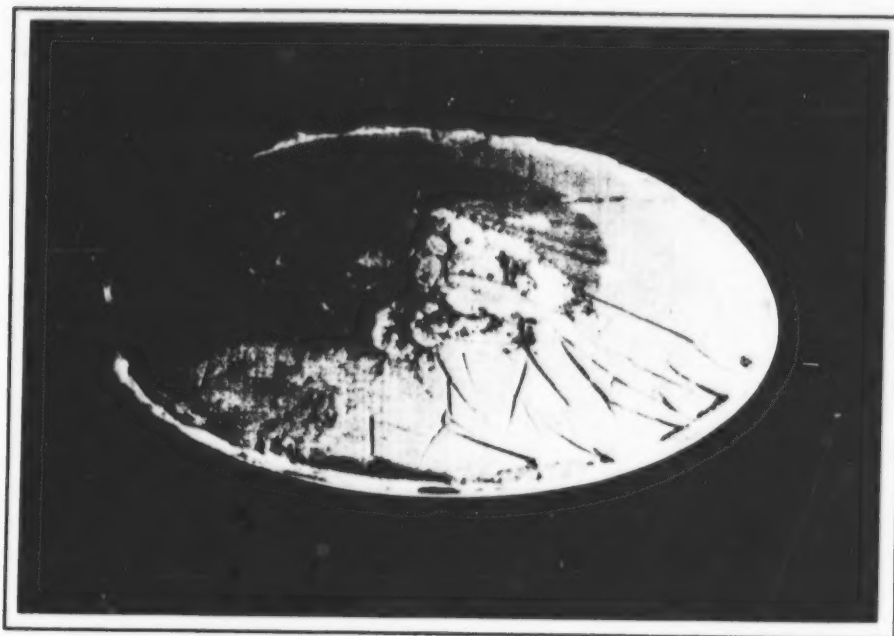


FIGURE 15

**LOOSE ASH PARTICLES ON THE SPECIMEN SURFACE
AS A RESULT OF MOVING A FINGER ACROSS
THE SURFACE (I.e. MINOR DISTURBANCE)**

APPENDIX I

Procedure For the "Modified Slump Test"

(Ref: H.S. Radhakrishna. "Development of
Fluidized Electrical Cable Backfills"
Canadian Electrical Association (CEA) Report
069 D 140, July 1982)

A.1 General

This method covers apparatus and procedures required for determining the flow of lean, low and high strength grout mixtures made with binders such as fly ash and cement along with an aggregate filler.

A.2 Apparatus

Mould - The test specimen shall be formed in a mould made of mild steel. The mould shall be a cylinder 76 mm inside diameter by 152 mm high, open at both ends. The minimum wall thickness shall be 5 mm.

Tamping Rod - The tamping rod shall be a round, straight metal rod, 10 mm diameter and approximately 200 mm long, with a hemispherical tip.

Test Plate - The test shall be carried out on a suitable metal plate to provide a uniform flowing surface. It should be of metal, of size 500 mm x 500 mm and of a suitable thickness to remain rigid. The test surface shall be plain and smooth.

Rulers - Two 30 cm rulers, graduated in mm shall be provided.

A.3 Sample

The sample of test mix shall be representative and obtained in accordance with CSA Specification CAN3-A23.2, method A23.2-1C (Sampling Plastic Concrete).

A.4 Procedures

Dampen the mould and place it in the centre of the dampened level test plate. Fill to overflowing with the test mixture and compact with 5 strokes of the tamping rod uniformly distributed over the cross section of the surface.

Strike off the surface of the test mixture, remove any material that falls in the area around the mould base, and wipe the test plate clean.

Lift the mould straight up slowly, allowing all of the material to flow out of the mould onto the base.

Determine the average diameter of the resulting flow by measuring the diameter across two points at 90° intervals.

Determine the maximum height of the flow material by standing the mould on the test plate adjacent to the flow material, resting the edge of one ruler across the diameter of the top of the mould and allowing it to extend out over the flow material, measure the minimum "slump" of the material. Subtract the minimum slump from the height of the mould, 152 mm, to determine the maximum height of the flow.

A.5 Report

Record the flow in terms of average diameter in mm to the nearest 5 mm.

Record the height of the flow, as measured in paragraph 8.4.5, to the nearest 5 mm.

Record any segregation of solids, bleeding at the edges or any other unusual conditions.

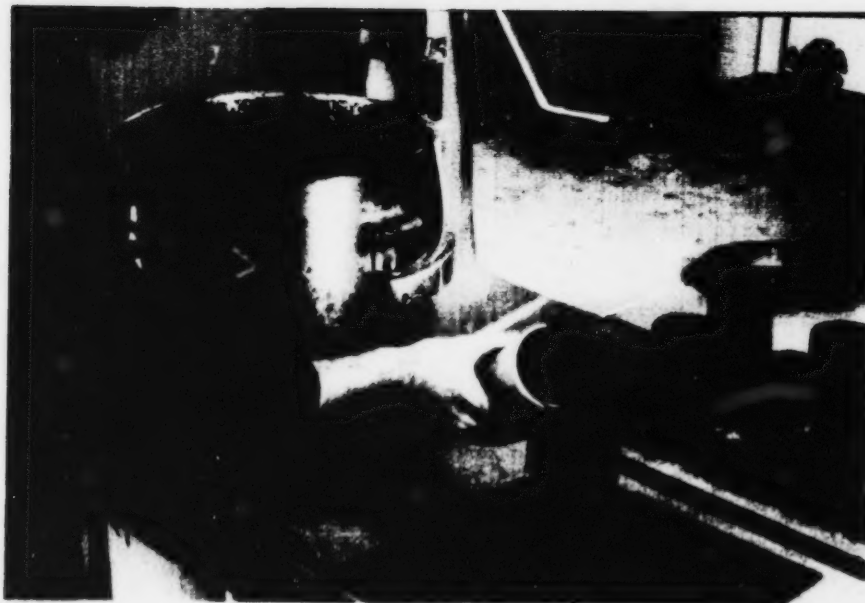


FIGURE A1 Pouring Fly Ash Slurry in a Steel Mold
Before Conducting a "Modified Slump Test"



FIGURE A2 Measuring the Diameter of a Slumped Pancake-like
Fly Ash Slurry. The specimen diameter is used as
a measure of the material's flowability.